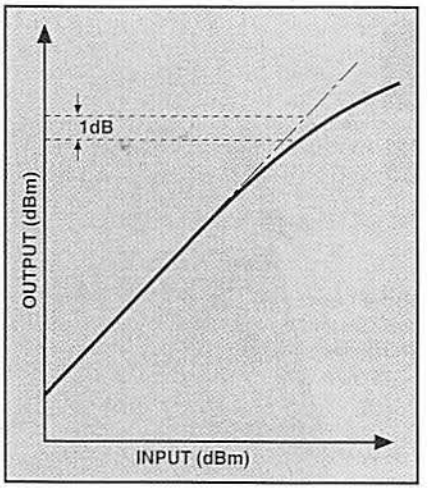

Figure 1. The 1dB compression point of an amplifier.

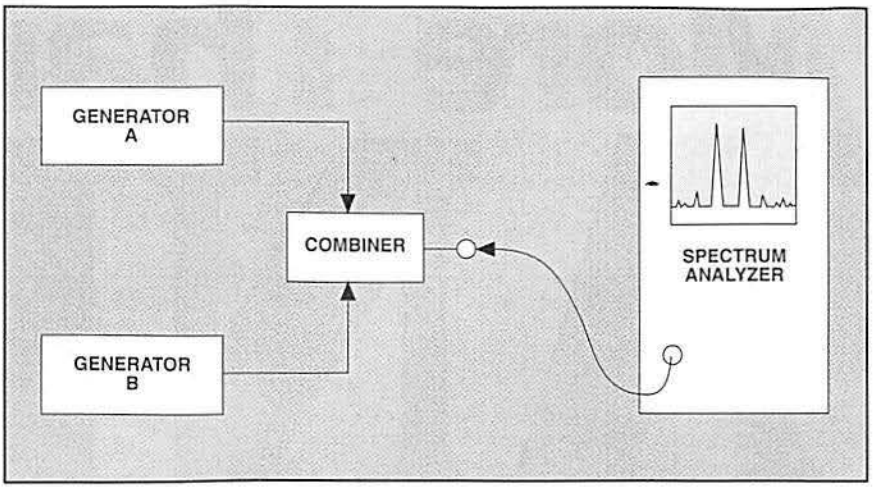

Figure 2. A simplified test setup for determining a spectrum analyzer's dynamic range.

Intermodulation distortion

By Harold Kinley, C.E.T.

An overdriven or overloaded amplifier distorts the signal it is intended to amplify. *Intermodulation distortion* (IMD) describes one type of distortion that results.

Figure 1 above left shows the result of overdriving an amplifier. With low input levels, the amplifier's output signal gives a true reproduction of the input signal. However, when the input signal reaches a certain level, *compression* begins. Note the point where the output signal is compressed by 1dB, which means that the output level increases 1dB less than the input level. For example, when a 3dB increase in the input level produces a 2dB increase in the output level, as illustrated in Figure 1, 1dB compression has occurred. Specifications for many amplifiers and other devices include the 1dB compression point.

When compression begins, IMD results. The IMD begins at a low level and rises rapidly as the input level increases beyond the point of compression.

Test setup

Figure 2 above right shows a simplified setup for measuring IMD produced in the spectrum analyzer. Essentially a sophisticated superheterodyne receiver, a spectrum analyzer can have the same problems as any other superheterodyne receiver. In this test setup, generators A and B generate two continuous wave (CW) tones at RF frequencies. A special combiner (not a simple "T" connector) combines their output and connects it to the spectrum analyzer input. When the input levels to the spectrum analyzer begin to overdrive or overload the analyzer, IMD occurs. Third-order IMD signals at frequencies of 2A – B and 2B – A form. (2A – B is two times the frequency of tone A minus the frequency of tone B.)

Highly accurate tests require a more complex test setup than depicted in Figure 2. For example, a low-pass filter should be inserted between each generator and the combiner to suppress harmonics, and a high degree of isolation must be provided to prevent interaction between the two generators. The combiner provides some

(continued on page 68)

Kinley, a certified electronics technician, is regional communications manager, South Carolina Forestry Commission, Spartanburg, SC. He is the author of *Standard Radio Communications Manual: With Instrumentation and Testing Techniques*, Prentice-Hall, 1985. He is a member of the Radio Club of America.

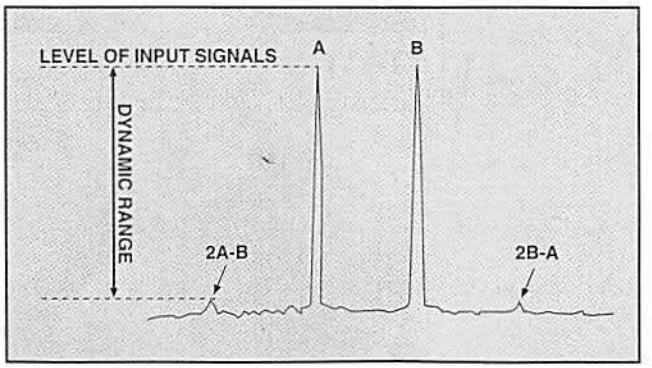

Figure 3. A spectrum analyzer's dynamic range equals the difference of the reference tones (A or B) and the level of the IM signals as the IM signals rise just above the spectrum analyzer's noise floor.

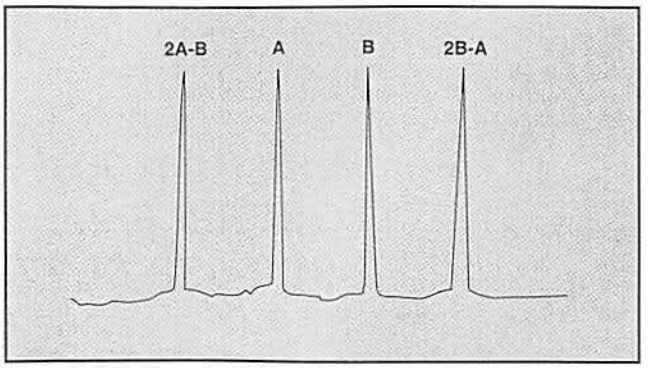

Figure 4. At the theoretical third-order intercept point, the level of the IM signals equals the level of the reference tones. Severe amplifier compression would prevent this condition from occurring in a practical amplifier.

(continued from page 8)

isolation, and more isolation could be obtained by inserting isolation amplifiers between the generator outputs and the combiner.

Of course, proper padding must be used to maintain a good impedance match throughout. Just remember, the setup shown in Figure 2 is a simplified version of the elaborate setup used in laboratories.

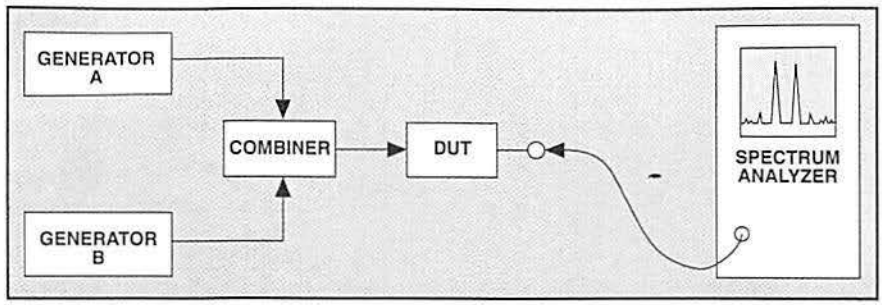

Figure 5. A device under test (DUT) is tested for third-order intermod using this simplified version of the laboratory setup. See text for information about the integrity of the test setup.

The whole purpose is to make sure that any IMD *caused by the test setup* is suppressed far below the IMD generated in the device under test (DUT)—in this case, the spectrum analyzer.

Dynamic range

Gradually increase the generators' outputs at equal levels until the third-order intermod products just begin to appear above the noise level on the spectrum analyzer display. At this point, the difference between the level of tone A (or B) and one of the intermod products (2A – B or 2B – A) is called the *dynamic range* of the spectrum analyzer. For example, when the difference between tone A and the 2A – B product is 70dB, the dynamic range of the spectrum analzyer is 70dB. (See Figure 3 on page 8.)

Third-order intercept

Once the intermod signals form, the levels of the IM signals increase rapidly as the level of the two tones increases. In fact, the level of the IM signals increases much more rapidly than the level of the fundamental tones (A or B). For this reason, theoretically, a point would be reached where the level of the IM signals would become equal to the level of the fundamental tones, A or B. (See Figure 4 on page 8.) This point is called the *third-order intercept point*. This point occurs when the input tones are increased about 15dB above the point of 1dB compression.

Remember, the third-order intercept point exists only *in theory*. In practice, an amplifier's compression prevents IMD signals from reaching this point. Regardless, the third-order intercept point is an important specification for amplifiers and receivers. It tells a lot about how the amplifier or device should be operated. Although higher-order intercept points could be specified, third-order intermod is the most prominent and therefore the most troublesome.

Figure 5 above shows how a typical

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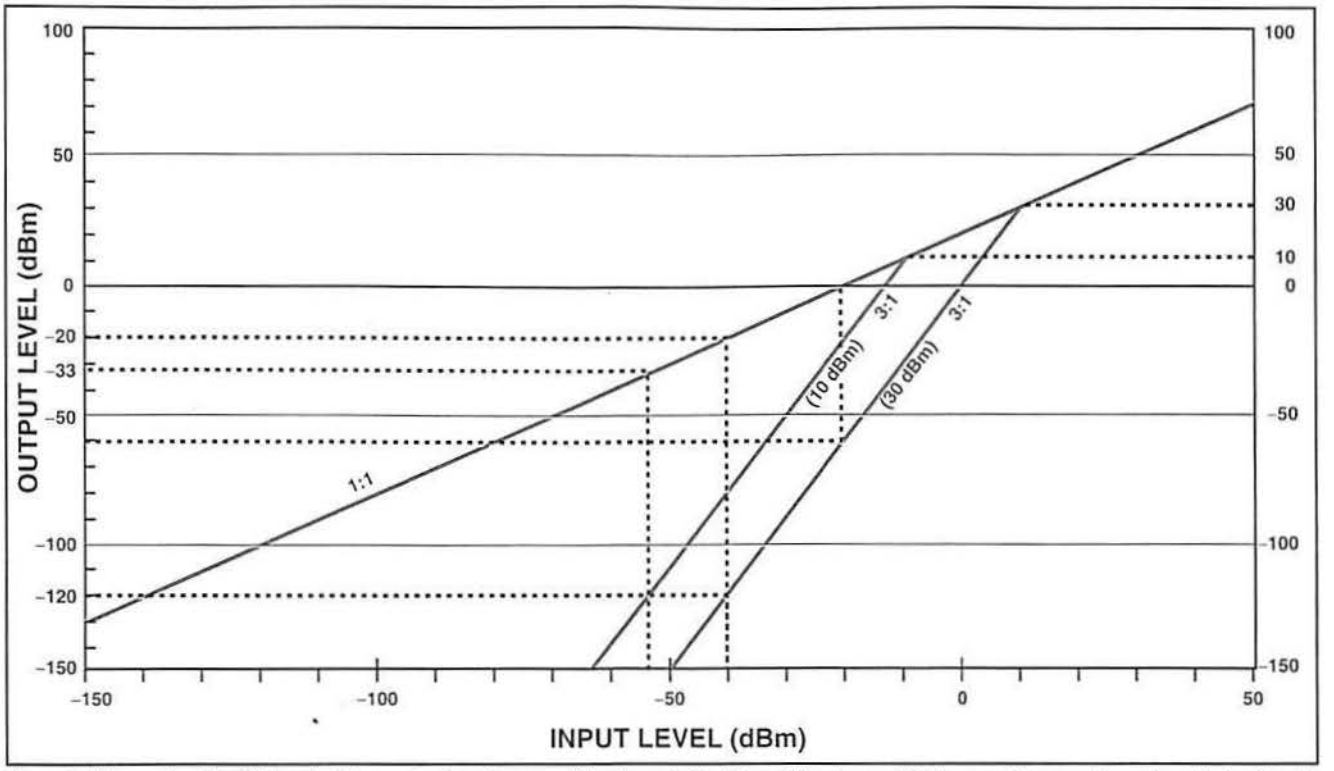

Figure 6. This graph of the third-order intercept point of two amplifiers is useful in determining the amplifier's operating conditions, input/output levels and IM levels. See text for details.

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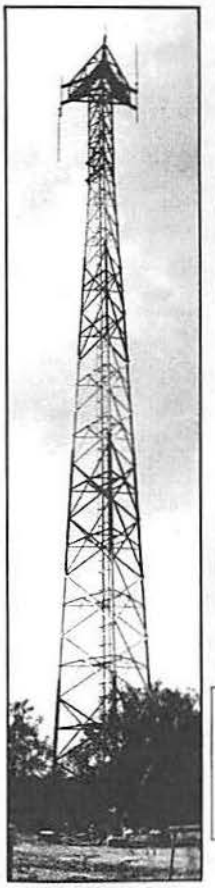

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DUT is tested. This configuration could represent receiver testing. The spectrum analyzer could be connected to the first IF amplifier's output or another such test point in the receiver. The test would include all circuits between the receiver input and the point of measurement. However, the first *active* device will be the main determining factor.

Third-order intercept graph

Figure 6 on page 69 shows the third-order intercept points for two amplifiers. Both amplifiers have 20dB gain. One has a third-order intercept point of +30dBm; the other has a third-order intercept point of +10dBm.

Notice that there are three graphs. One represents the amplifier's linear output vs. input—the 1:1 ratio line that means that the output (vertical scale) changes 1dB for each 1dB change in input (horizontal scale). The other two lines representing the intermod signals have a 3:1 slope, which means that, with a 1dB change in the input level, the output level will change by 3dB. The point where the 3:1 graph intersects the 1:1 graph is the third-order intercept point. Notice that one point is at +30dBm, and the other is at +10dBm.

Third-order intercept formulas

These formulas take into account the DUT's gain and are based on the input signal levels.

$$I_P = \left(\frac{3(P_{Ai} + G) - P_3}{2}\right) \quad (1)$$

$$P_3 = 3(P_{Ai} + G) - 2I_P \quad (2)$$

$$P_{Ai} = \left(\frac{(P_3 - 3G = 2I_P)}{3}\right) \quad (3)$$

where

P_3 = power (dBm) in third-order intermod signal.

P_{Ai} = power (dBm) of either tone A or tone B at the *input*.

G = gain (dB) of amplifier.

I_P = third-order intercept point (dBm).

These formulas represent the levels of tone A and tone B at the point where the spectrum analyzer is connected.

$$I_P = \left(\frac{3P_A - P_3}{2}\right) \quad (4)$$

$$P_3 = 3P_A - 2I_P \quad (5)$$

$$P_A = \left(\frac{(P_3 + 2I_P)}{3}\right) \quad (6)$$

where

P_3 = power (dBm) of third-order intermod signal.

P_{Ai} = power (dBm) of either tone A or tone B.

I_P = third-order intercept point (dBm).

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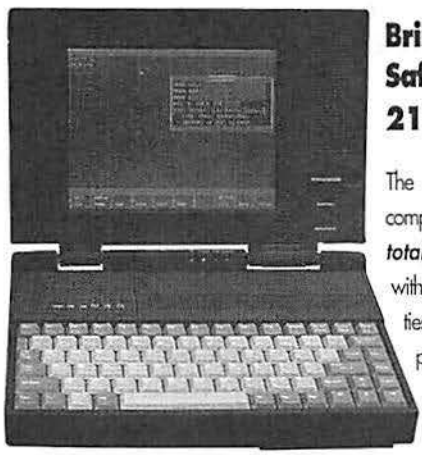

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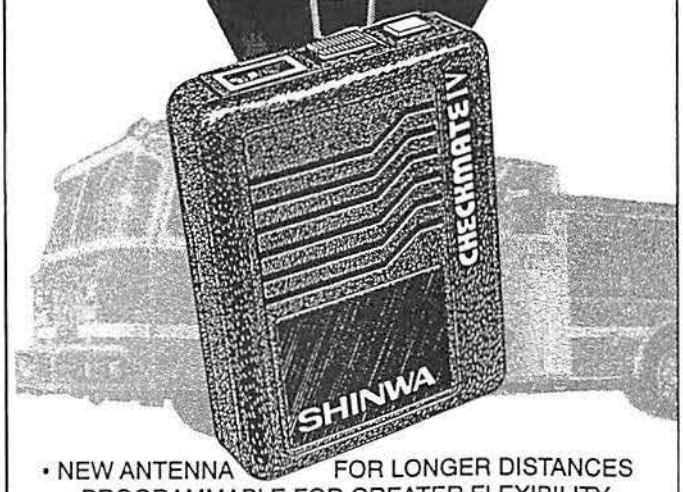

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The graph takes into account the amplifier's 20dB gain. For example, an input level of –40dBm (horizontal scale) corresponds to an output level of –20dBm (vertical scale).

Suppose a receiver has a sensitivity of –110dBm or 0.7μV. To prevent the third-order IM signal from degrading the reception of a –110dBm signal, the IM signal should be suppressed at least 10dB *below the desired signal level.* In this case, the third-order IM signal should be no greater than –120dBm to prevent any interference to the desired signal.

To determine the maximum input/output level that the have two tones can reach before causing distortion, a line is drawn from the –120dBm point on the vertical scale to intersect the IM slopes. Then, vertical lines are drawn up to the 1:1 slope and down to the horizontal scale. These lines are shown as dashed lines in Figure 6. The dashed lines intersect the 1:1 slope at the –20dBm point for the +30dBm slope and at –33dBm for the +10dBm slope.

The IMD ratio can be defined as the difference in the level of the desired tone (A or B) and the level of the third-order IM signal measured in decibels.

Similarly, the dashed lines intersect the horizontal scale at –40dBm for the +30dBm slope and –53dBm for the +10dBm slope. Thus, for the +30dBm slope, the output level of tone A or B should be no greater than –20dBm, and the input level to the amplifier should be no greater than –40dBm.

For the +10dBm slope, the output level of tone A or B should be no greater than –33dBm, and the input level should be no greater than –53dBm. If the input/output levels exceed these limits, the third-order IM signal will exceed the –120dBm level and will degrade the –110dBm desired signal.

IMD ratio

The IMD ratio can be defined as the difference in the level of the desired tone (A or B) and the level of the third-order IM signal measured in decibels.

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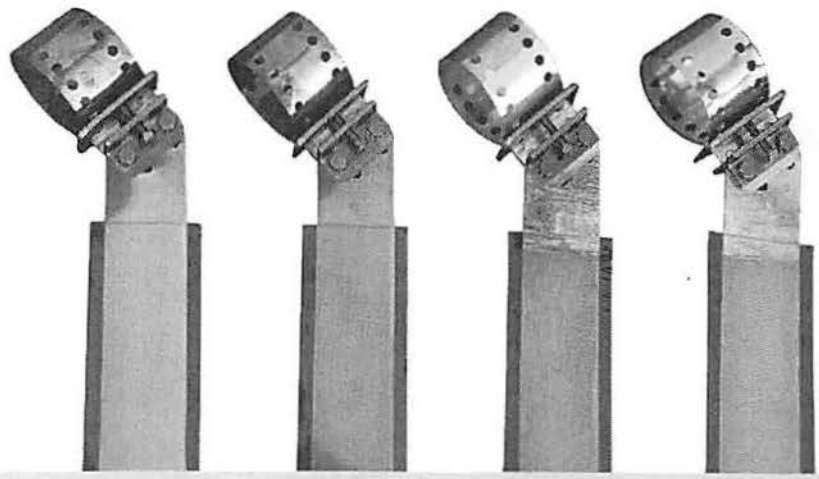

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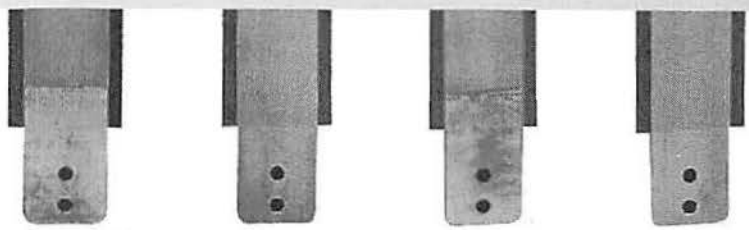

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The IMD ratio must be specified at a given input or output level because the IMD ratio becomes worse as the input/output level increases.

Take the case of the 20dB amplifier with the +30dBm third-order intercept point. When the output level of tone A or B is –20dBm, the level of the third-order IM signal is –120dBm. This difference represents an IMD ratio of (–20) – (–120) = 100dB.

Now, look at the case for an output level of 0dBm. As shown by the dashed line, the third-order IM signal is –60dBm. Thus, the IMD ratio is now 60dB. The ratio gets worse fast as the input/output level increases!

Formulas

You can use formulas listed on page 70 to make calculations involved with third-order intercept. Formulas 1-3 take into account the DUT's gain and are based on the *input* signal levels. This means that the spectrum analyzer used to study the intermod is connected to the *output* of the device, and the signal levels used in the formulae (P_{Ai}) are the levels of the tones (A or B) at the input to the device.

Formulas 4–6 represent the levels of the tones (A or B) at the point where the spectrum analyzer is connected. These examples demonstrate the practical use of the formulas.

Example: The DUT is an RF amplifier with 20dB gain and a +20dBm third-order intercept point. The level of the third-order IM signals must be kept to no more than –60dBm. What is the maximum level of tone A or B short of causing IM signals greater than –60dBm?

Solution: Use Formula 3 on page 70 and substitute values from the example.

$$P_{Ai} = \left[\frac{-60 - 3(20) + 2(20)}{3}\right]$$

$$= \left(\frac{-80}{3}\right)$$

$$= -26.7dBm$$

Example: The DUT is an RF amplifier. A spectrum analyzer connected to the output shows the third-order IM signal at a level of –60dBm and the level of tone A at –10dBm. What is the third-order intercept point?

Solution: Use Formula 4 on page 70 and substitute values from the example.

$$I_P = \left[\frac{3(-10) - (-60)}{2}\right]$$

$$= \left(\frac{+30}{2}\right)$$

$$= +15dBm$$

Next time, we will look at intermodulation from a different perspective and learn how to take advantage of the behavior of the third- and higher-order intermodulation process to gain an advantage in suppressing it. *Stay tuned!*

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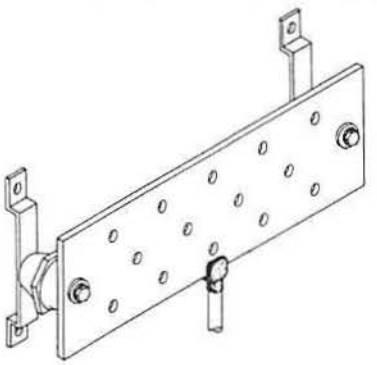

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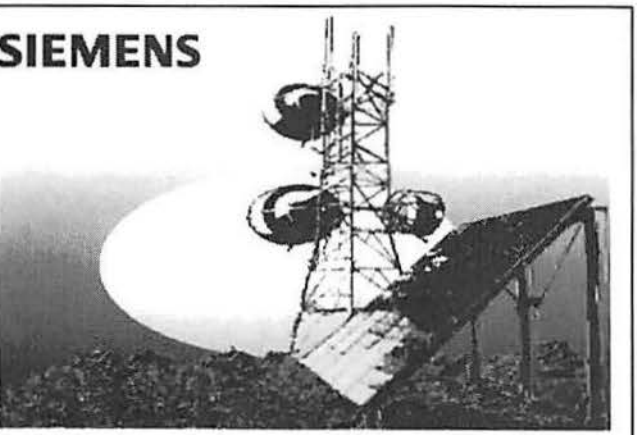

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More about intermodulation

By Harold Kinley, C.E.T.

Last month, we discussed third-order intercept and two-tone intermodulation testing using two equal-level, single-tone signals (A and B) to produce the intermod (IM) signal. Though two equal level tones (A and B) are used in third-order intermod testing of amplifiers and receivers, in the real world the mixing signals are rarely of equal level. In fact, one of the mixing signals usually has a much higher level than the other(s).

This discussion is limited to two-signal, third-order intermodulation. Though higher orders of intermod are often encountered, and more than two mixing signals can be involved, the third-order, two-signal IM is usually the most troublesome.

Calculating IM level

The formulas in the box above can be used to determine how unequal-level tones (A and B) produce unequal IM signals, 2A – B and 2B – A. (The formulas also work for equal-level, two-tone signals). Furthermore, the power in the two IM signals can be determined from the power level of the two-tone mixing signals, A and B, and the third-order intercept point of the amplifier or other device under test (DUT).

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Formulas for calculating IM levels

$$P_{(2A-B)} = 2P_A + P_B - 2P_{I3}$$

$$P_{(2B-A)} = 2P_B + P_A - 2P_{I3}$$

where: $P_{(2A-B)}$ = power level of IM signal in dBm
$P_{(2B-A)}$ = power level of IM signal in dBm
P_A = power level of signal A in dBm
P_B = power level of signal B in dBm
P_{I3} = power level of third-order intercept in dBm

Figures 1 and 2 below show how two unequal tones, A and B, produce two unequal IM signals, 2A – B and 2B – A, at the output of an amplifier with a third-order intercept point of +30dBm. In Figure 1, tone A is at +10dBm, and tone B is at –10dBm. The 2A – B IM signal is at –50dBm, whereas the 2B – A IM signal is at –70dBm. Figure 2 shows a reverse of the levels of the two tones: A is at –10dBm, and B is at +10dBm. Notice how the two IM signals are reversed from Figure 1. From this comparison, we can see that the higher of the two IM signals, 2A – B or 2B – A, is always nearest the higher level tone, A or B.

The graph

Figure 3 on page 79 is handy for calculating third-order IM levels when the levels of the two tones, A and B, are known. The graph is for an amplifier or other device with a third-order intercept point of +30dBm; however, it can be used for amplifiers with third-order intercept points other than +30dBm by applying an adjustment factor.

There are two horizontal scales at the top and bottom of the graph. The top horizontal scales are where the IM signal level is read. The bottom horizontal scales represent the level of the second-order term, A or B. For example, if the IM is formed from $2A - B$, then the term A is the *second-order* term, and the term B is the *first-order* term, and the resulting IM level found on the top horizontal scale would represent the $2A - B$ IM signal level. Conversely, if the IM is formed from $2B - A$, then the B term is the *second-order* term, and the A term is the *first-order*, with the resulting IM level found at the top horizontal scale representing the $2B - A$ IM level.

The *right* vertical scale of the graph represents the first-order term of the IM signal. The major divisions represent 10dB increments.

The *left* vertical scale of the graph can be used to adjust for third-order intercept points other than +30dBm. The

(continued on page 79)

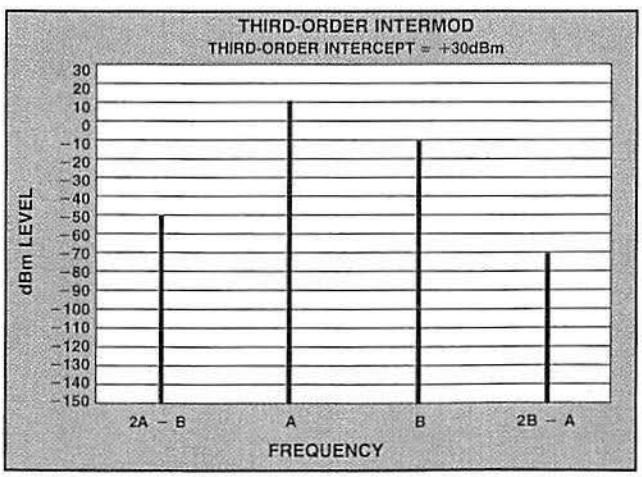

Figure 1. Signals A and B mix to form IM signals 2A – B and 2B – A. Note that the higher-amplitude IM signal is nearest to the higher-amplitude mixing signal, A.

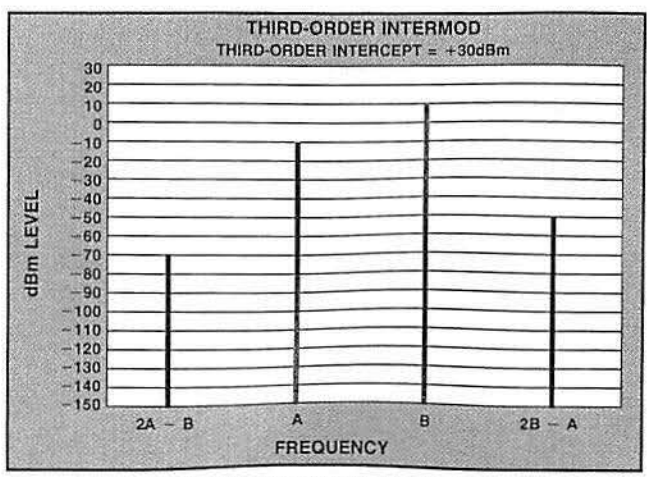

Figure 2. The mixing signals, A and B, are reversed from Figure 1. Now, the higher-amplitude mixing signal is B. Again, the higher-amplitude IM signal (2B – A) is nearest to the higher amplitude mixing signal, B.

(continued from page 8)

major divisions represent 5dB increments. For the +30dBm third-order intercept point, no adjustment is necessary.

Using the graph

A few examples illustrate how to use the graph. Looking back at Figure 2, let's use the graph to determine the levels of the *2B – A* and the *2A – B* IM signals. In the case of 2B – A, *B* (+10dBm) is the *second-order* term, so locate *B* on the lower horizontal scale. Now move up as shown by the red dashed line to intersect the graph at point 1. Now, to take into account the *first-order* term, *A* at –10dBm, move down (down for negative, up for positive) 10dB to point 2 and back over to intersect the graph at point 3. From point 3 move up to the horizontal scale to find the level of the *2B – A* IM signal is –50dBm.

The level of the 2A–B IM signal is found similarly. This is shown by the blue dashed line on the graph. This time, the *second-order* term is *A*, and the *first-order* term is *B*. The *second-order A* term (–10dBm) is located on the bottom horizontal scale. From here, move up to intersect the graph at point 1. Now, to take into account the *first-order B* term (+10dBm), move up 10dB to point 2 on the graph. Now move back over to intersect the graph at point 3 and up to the top horizontal scale at –70dBm. Thus, –70dBm is the level of the third-order (2A – B) IM signal.

Here is an example using an amplifier with a third-order intercept point of

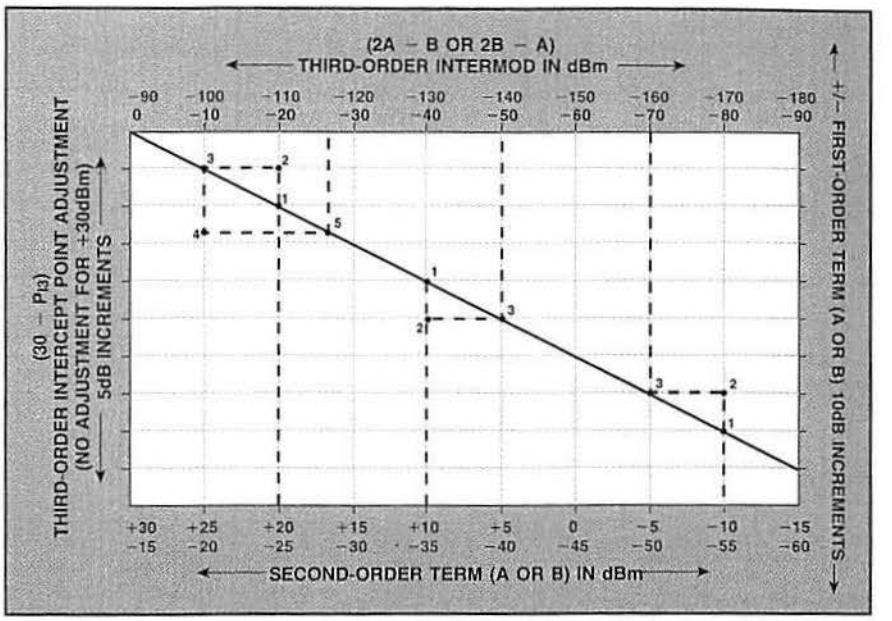
(2A – B OR 2B – A)
THIRD-ORDER INTERMOD IN dBm
THIRD-ORDER INTERCEPT POINT ADJUSTMENT (NO ADJUSTMENT FOR +30dBm) 5dB INCREMENTS (30 – P3)
+/– FIRST-ORDER TERM (A OR B) 10dB INCREMENTS
SECOND-ORDER TERM (A OR B) IN dBm

Figure 3. This graph can be used to determine the amplitude of third-order, two-signal IM signals such as 2A – B or 2B – A. See text for instructions on using the graph.

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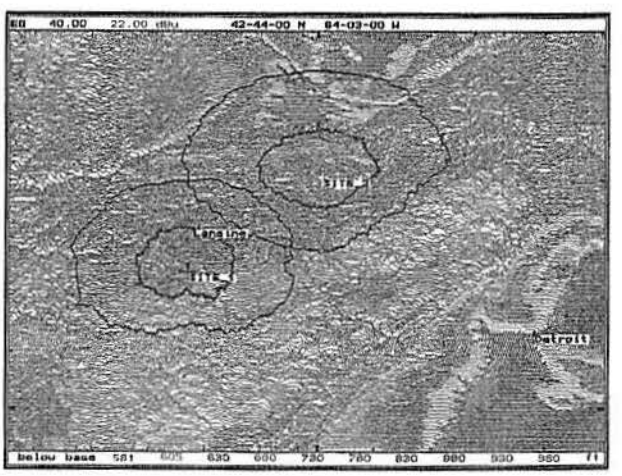

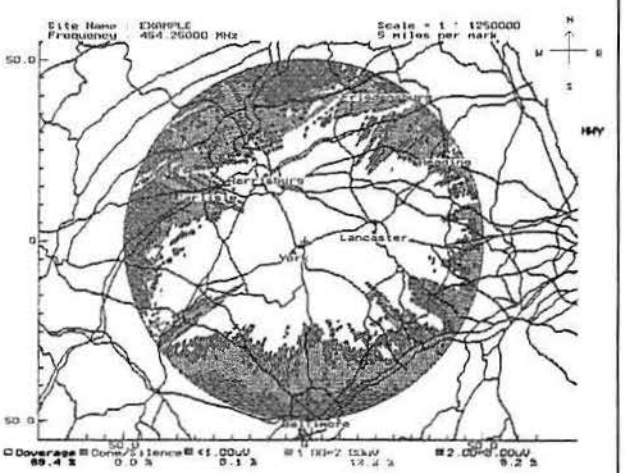

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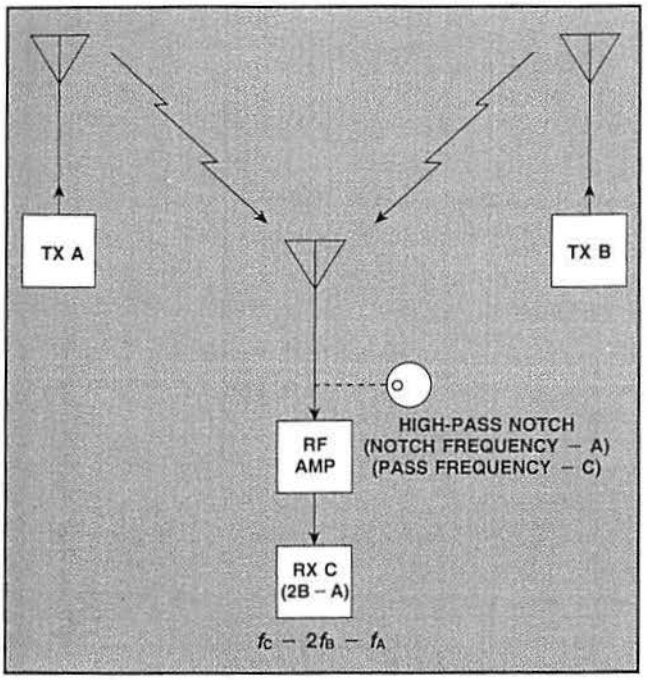

Figure 4. (to the left) Signals from transmitters A and B are mixing in receiver C to produce an IM "hit" on receiver C. (C = 2B – A). A high-pass notch filter shown in dashed line can be connected to the line at the receiver to suppress the IM signal to a non-interfering level.

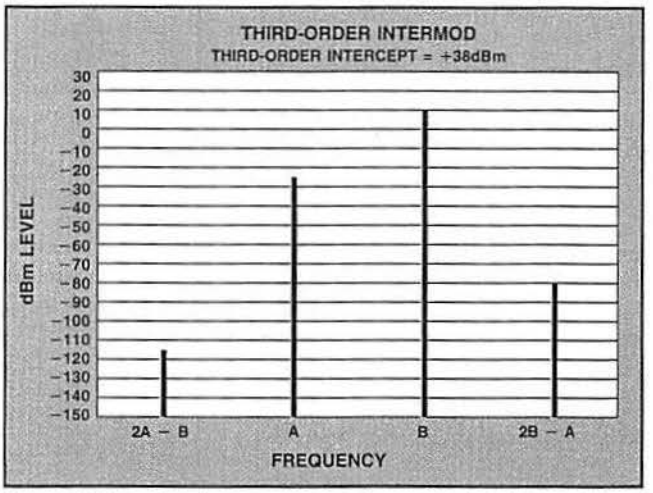

Figure 5. These signals are present at the output of the RF amplifier of Figure 4. Note that the level of the 2B – A IM signal is at an amplitude of –80dBm. This would overide the desired signal at a level of –106dBm.

+38dBm (a high-quality amplifier). The signal levels at the output of the amplifier are as follows: signal *A* is –25dBm, and signal *B* is +10dBm. What is the level of the $2A - B$ IM signal? First, locate –25dBm on the lower horizontal scale, and from there move up to the graph at point 1. Now, to account for the +10dBm level of signal *B*, move upward 10dB to point 2. Now move back to the graph line at point 3. Because the third-order intercept point of this amplifier is +38dBm instead of

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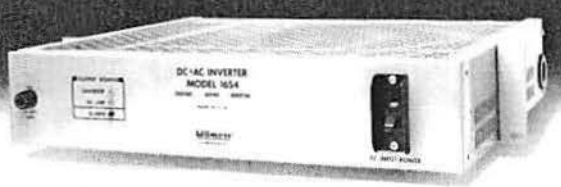

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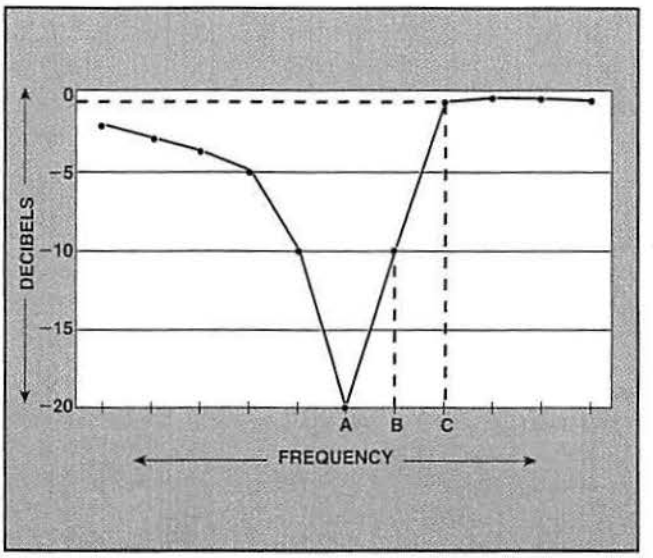

Figure 6. The frequency response of the cavity filter used in Figure 4 is shown here. Note that the signal from transmitter A is reduced by 20dB at the input to the receiver amplifier, whereas the signal from transmitter B is reduced by 10dB. The insertion loss at receiver frequency C is less than 1dB.

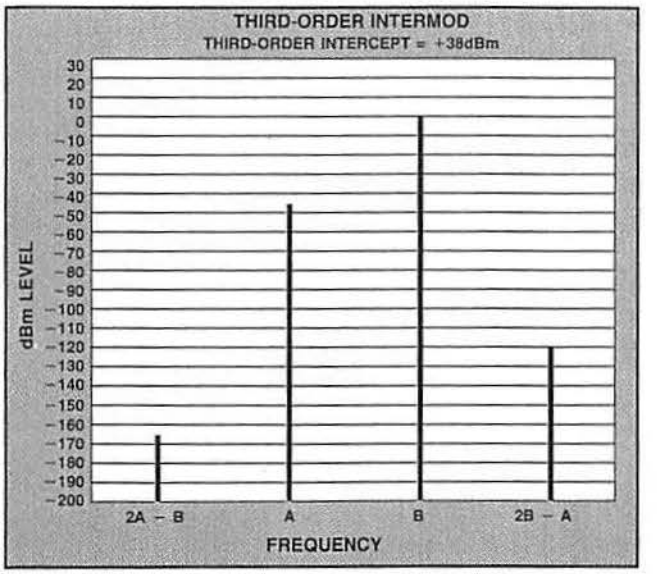

Figure 7. This is the level of the various signals at the Figure-4 RF amplifier's output after the high-pass notch filter is connected. Note that the 2B – A IM signal is now reduced to –120dBm, resulting in little or no interference to the desired signal.

+30dBm, we must adjust for the difference. The adjustment will be 30 – 38 = –8dB. So, from point 3 on the graph, move down 8dB according to the left vertical scale to point 4. Next, move over to the graph line to point 5. From here, move vertically to the top horizontal scale to a reading of –116dBm. This is the level of the $2A - B$ IM signal.

Receiver IM suppression

Figure 4 on page 80 shows signals from

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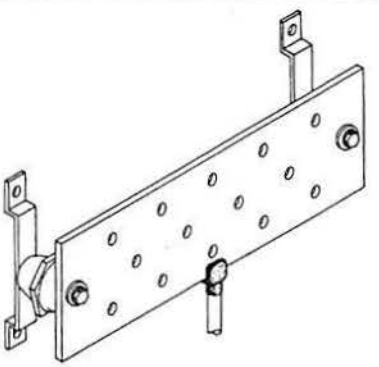

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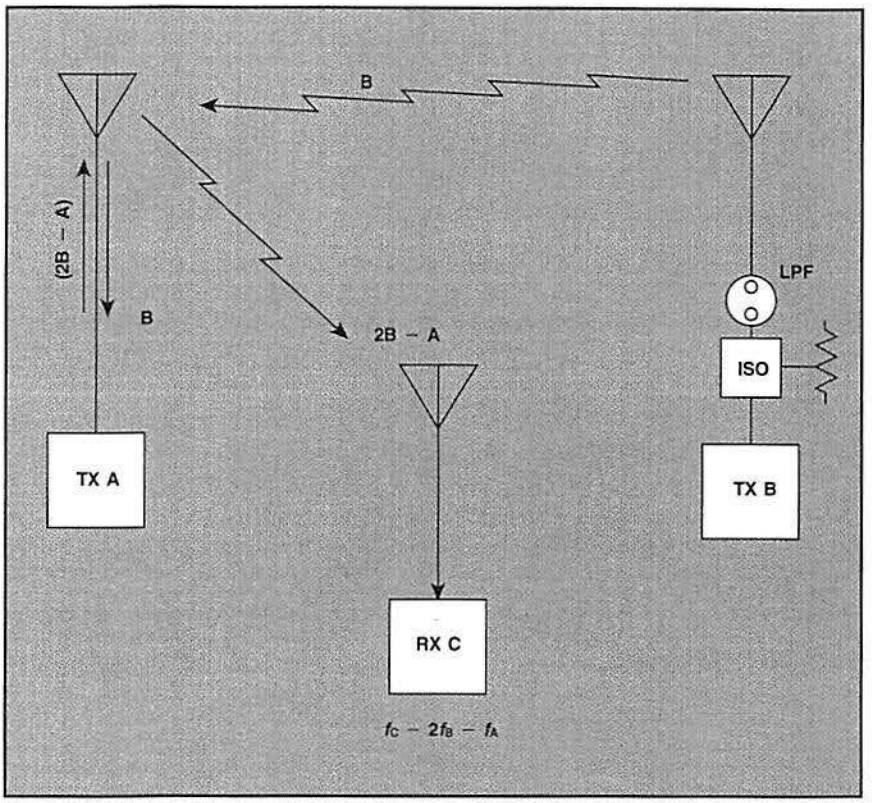

Figure 8. In this situation, the IM signal is being produced in the class C RF power amplifier of transmitter A. The IM signal can be suppressed by installing a proper isolator on the transmission line at transmitter A.

transmitter A and B mixing in the front end of receiver C. The frequency combination of 2B − A happens to be right on the receiver frequency C. The levels of the various signals as they appear at the output of the RF amplifier of receiver C are shown in Figure 5. Suppose that it is desired that the receiver be able to receive a 0.35μV signal on frequency C, (2B – A) with minimum degradation caused by the IM signal. Suppose further that the RF amplifier's gain is 10dB.

This means that, with a 0.35μV (−116dBm) signal at the input of the receiver RF amplifier, the output of the desired signal from the amplifier will be −106dBm. Note that the level of the *2B – A* IM signal at the RF amplifier output is −80dBm. This is 26dB *above* the level of the desired signal. A high-pass notch filter is placed on the line at the receiver RF amplifier input to suppress the IM signal to a non-interfering level. (See dashed line in Figure 4.)

The frequency response of the high-pass notch filter is shown in Figure 6 on page 81. Note that the level of signal A is attenuated by 20dB, and the level of signal B is attenuated by 10dB. So what happens to the level of the IM signal at the output of the RF amplifier?

Figure 7 on page 81 shows the levels of the various signals at the RF amplifier output after a high-pass notch filter is installed on the line before the receiver input. Note that the level of the interfering IM signal is now −120dBm. Remember, the level of the desired signal was −106dBm. So, even with the slight insertion loss of the filter at the desired frequency, the IM signal is now suppressed approximately 13dB below the desired signal and should not cause any significant degradation of the desired signal.

Transmitter IM suppression

Figure 8 above shows a situation in which transmitter-produced intermodulation is producing an IM hit on an on-site receiver.

Note that an isolator and low-pass filter are inserted in the line between transmitter B and the antenna. The isolator provides a high degree of suppression for any signal traveling from the antenna back toward the transmitter. The signal traveling in this direction is "dumped" into the load resistor and dissipated as heat. The low-pass filter serves to suppress the harmonics that might be generated by the isolator.

Note that transmitter A has no isolator in the line. The signal from transmitter B at the antenna can come down into the transmitter's class C power amplifier and

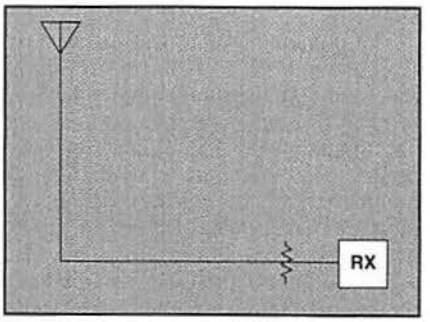

Figure 9. A simple attenuator pad can be inserted in the line at a receiver to determine whether the IM signal is receiver produced or radiated from another source. See text for details.

mix with the signal of transmitter A to produce an IM signal that will interfere with receiver C. To suppress the IM signal to a non-interfering level, an isolator should be installed in the line of transmitter A along with a low-pass filter to suppress any harmonics generated by the isolator.

Receiver-produced IM

Before setting out to suppress IM interference, you must first know where it is being produced. Is it being produced in the front end of the receiver, or is it being produced externally and radiated to the receiver antenna from another source? One simple way to decide is to use an attenuator pad connected before the receiver input. (See Figure 9 above.) If the IM signal is third-order and is being produced inside the receiver, the attenuation of the IM signal will be three times the pad attenuation value.

For example, if a 3dB pad is inserted into the line, the receiver-produced third-order, two-signal IM will be reduced by 9dB. Unfortunately, the desired signal will be attenuated by 3dB, but we gain the advantage of a 6dB difference with the IM signal. A fifth-order, two-signal IM product will be reduced by 15dB. If the IM signal drops less than the expected amount but more than the pad attenuation, the IM signal is probably a combination of receiver-produced and radiated IM.

There is much more to be written about intermod than can be included in this space. This column has only scratched the surface; however, there is a book dedicated to the subject of intermodulation control. The book, *Intermod Control,* was written by William F. Lieske Sr., president of EMR, Phoenix, AZ. Lieske is a recognized authority on the subject of intermodulation control. The book is available from Wiesner Publishing. Individual copies can be ordered for $10 postpaid with a check or money order made out to Wiesner Publishing, Attention Mike Peterman, 7009 S. Potomac, Englewood, CO 80112; tel. 303-397-7600; fax 303-397-7619.

A large, functional version of the graph in figure 3 is available from the author for $2.00 post-paid.

A computer program that is useful in calculating IM hits and third-order, two-signal IM is available from the author for $12.50 plus $2.50 for shipping and handling. These programs run from MS-DOS on a PC and are available on a 3.5" or 5.25" floppy diskette. You may write the author at 204 Tanglewylde Drive, Spartanburg, SC 29301-2949.

Stay tuned!

References

1. Christiansen, Donald, and Donald G. Fink, *Electronics Engineer's Handbook, 3rd edition,* 1989, McGraw-Hill, New York

2. Lieske, William F. Sr., *Intermod Control,* 1984, Wiesner Book Company, Littleton, CO.

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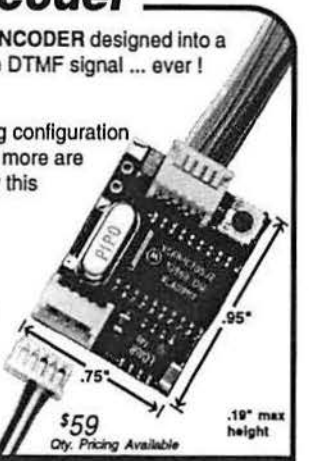

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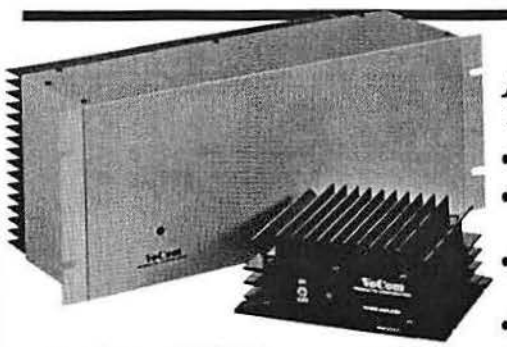

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